Galaxies

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Abstract

Among all astronomy topics, our group are especially interested in the interaction between the galaxies. Therefore in this project, we are going to focus on the colliding galaxies. Galactic collisions, in fact, are relatively common in the universe. We can find many real examples when we look up into the sky. Using computers, we are able to build up a model demonstrating the collision between galaxies. We will begin with a brief introduction of colliding galaxies and then show how we have been able to simulate them using computer programs and compare them with real examples.

1. Introduction

In all types of interactions between galaxies, galactic collisions are very common in the universe. The probability of a collision is high. If we compare the space between the galaxies to their sizes we find that, on the average, they are separated by about 10 to 100 times of their diameter. Hence, there would be a large number of collisions.

Large telescopes reveal hundreds of galaxies that appear to be colliding with other galaxies. One of the most famous pairs of colliding

galaxies, NGC4038 and NGC4039, are called "The Antennae", because their long tails resemble the antennae of an insect. In our project, we write a computer program to simulate similar collisions.

When two galaxies collide, in fact, the stars within them will just glide past one another without any physical contact whatsoever. Although the individual stars will not collide, they will feel the overall gravitational pull of the other galaxy and the resulting tidal force will perturb many of them from their orbits. In some cases, they will be forced into an orbit closer to the center of the galaxy; in other cases, they will be forced into orbits farther out. There will be a change in speed when a star changes orbit. As a result, as the star continues to move, the overall galaxy will begin to change shape.

The perturbation of each star depends only on the gravitational field it feels, and this force is given as follows:

Gravitational force $\quad F = \dfrac{GMm}{r^2},$

Gravitational filed $\quad g = \dfrac{GM}{r^2}.$

If we know how massive the two galaxies are, how many stars they contain, how fast they are approaching one another, and how they are spinning, then using computers, we should be able to calculate exactly what will happen when they collide.

2. Galaxies

2.1. Factors affecting galactic collisions

There are many different theories surrounding colliding galaxies, and there are many different factors to consider when studying them. The

outcomes of the collisions are dependent on the sizes of the galaxies, their shapes, speeds, composition, and the angle at which they collide.

2.2. Distance of galaxies

Galaxies are separated in distance units of megaparsecs (Mpc), where 1Mpc = 1 million parsec = 3.26 million ly. To determine distances of this magnitude, astronomers look for Cepheid variable stars in galaxies. After measuring the period and apparent magnitude of the Cepheid variables, they can determine the distance of the galaxies. Hence Cepheid variables are known as distance indicators.

2.3.) Method of determining the mass of galaxies

The Sun's orbit around the Milky Way tells us the amount of mass inside its orbit. If the Sun rotates with a period p in years and has an orbital size of a in AU, then the mass of the Milky Way within the orbit of the Sun is, in solar masses:

$$M = \frac{a^3}{P^2}.$$

3. The Model

The programme consists of a two dimensional demonstration of collisions between two circular galaxies, and each of them respectively consists of N and N_1 "particles" which appear in the form of a dot in the animation programme. N and N_1 can be adjusted. All of them have the same mass. The steps of the program is shown as follows:

1.) The positions of the centers of galaxies were defined.

2.) The positions of all the stars were defined. They were arranged in circles and each of the circles was concentric with the center of the galaxies.

Each circle was composed of stars which were equally separated. The larger the orbit was, the more stars the circle had.

3.) The initial x- and y- *components of the velocities* of the stars were defined. They were found by requiring the centripetal acceleration of a star to be exactly provided by the gravitational attractive forces between the star and the other stars.

4.) The accelerations of the stars were updated by calculating the total gravitational forces acting on each star and using Newton's second law. The new velocities and thus the positions were found. In a small time step Δt, the information was renewed and the positions of the stars at the later time were obtained according to the equations

$$a_{ix}(t) = \frac{F_{ix}(t)}{m_i} = \sum_{j \neq i} \left\{ \frac{Gm_j}{r_{ij}(t)^2} \cos q_{ij}(t) \right\} = \sum_{j \neq i} \left\{ \frac{Gm_j}{r_{ij}(t)^3} (x_i(t) - x_j(t)) \right\}$$

$$a_{iy}(t) = \frac{F_{iy}(t)}{m_i} = \sum_{j \neq i} \left\{ \frac{Gm_j}{r_{ij}(t)^3} \sin q_{ij}(t) \right\} = \sum_{j \neq i} \left\{ \frac{Gm_j}{r_{ij}(t)^3} (y_i(t) - y_j(t)) \right\}$$

$$x_i(t + \Delta t) = x_i(t) + v_{ix}(t)\Delta t + \frac{1}{2} a_{ix}(t)\Delta t^2$$

$$y_i(t + \Delta t) = y_i(t) + v_{iy}(t)\Delta t + \frac{1}{2} a_{iy}(t)\Delta t^2$$

$$v_{ix}(t + \Delta t) = v_{ix}(t) + a_{ix}(t)\Delta t$$

$$v_{iy}(t + \Delta t) = v_{iy}(t) + a_{iy}(t)\Delta t$$

where $(F_{ix}(t), F_{iy}(t))$ is the force acting on particle i with mass m_i, $(x_i(t), y_i(t))$ and $(v_{ix}(t), v_{iy}(t))$ are its position and velocity at time t respectively. The force is due to the gravitational attraction of other particles.

5.) The data was then analyzed and demonstrated by the animation programme and a number of figures were obtained.

6.) The figures could be used to indicate the influences of stars due to the

collision of galaxies and the appearance of the galaxies would also be found. The result could help people understand more about what is really happening during the collisions of galaxies.

4. Results

Fig. 1: NGC 4038/9, known as "Antennae." These two spiral galaxies are seen together on the left and zoomed in on the right.

In order to produce narrower filaments and bridges which are closer to the real case of "the Antennae", as shown in Fig. 1, the following conditions were required:

1. The two galaxies have to approach one another at a relatively slow speed.
2. They have to penetrate one another, but not too deeply.
3. Furthermore, the approaching galaxies have to approach in roughly the same direction as the other one spins.

4. One of the galaxies must have a smaller mass than the other.

Taking into account these factors, we observed an event of galactic collision sharing many similar features with that of the "Antennae". The results were recorded in the accompanying animation.

5. *Limitations of the model*

There are several limitations of our computer model. First, it is only a two-dimensional demonstration of the galactic collision, but actually, the stars in the galaxies do not completely lie on the same plane. As a result, the model does not consider the 3-D component of the gravitational attractive forces exerted by other stars in the galaxies.

Second, the model has not considered the large halo of *dark matter* present in the spiral galaxies. In fact, there is up to 10 times as much dark matter in the halo as there was in the visible part of the galaxy. And the effect of the mass of the dark matter was really significant.

Furthermore, we have not considered other cases of galactic collisions, which are shown in Figs. 2 and 3.

Fig. 2. Mass Transfer

Galaxy pair NGC 1409/10, which is an example of a mass transfer from NGC 1410, a spiral galaxy (on the lower left), to NGC 1409, a lenticular galaxy.

Fig. 3. The Cartwheel Galaxy

It forms when a galaxy is being hit by a smaller galaxy perpendicularly through the center. In this example, it is not clear which of the two smaller galaxies nearby did this.

6. Proposed Improvements

1. The number of test particles (stars) used should be increased significantly in order to get a more realistic animation, which is closer to the real case of the galaxy.

2. Since we can calculate the velocities, accelerations and positions of the particles by cutting the time to many very small intervals only, the time step must be as small as possible in order to simulate a more actual demonstration. Otherwise, we can use integration to calculate the velocities, accelerations and positions.

3. In the simulation, we assume the mass of the galaxies concentrates on some points and we just calculate the motion of these points only More realistically, each point should be set as small and light as possible, and they should not be evenly distributed.

7. Conclusion

From this research, we understand how the "Antennae" can be formed in the collision of galaxies. However, there are still many things that can be improved to increase the accuracy of the model. Limitations of the model and proposed improvements are listed in the discussions in Sections 5 and 6. We anticipate that improved computer models can provide further insights into how galaxies interact with each other.

Acknowledgements

References

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